

EFFECT OF TEMPERATURE AND PRESSURE  
ON THE CARBONATION OF WATER

BY

W. L. MARX

ARMOUR INSTITUTE OF TECHNOLOGY

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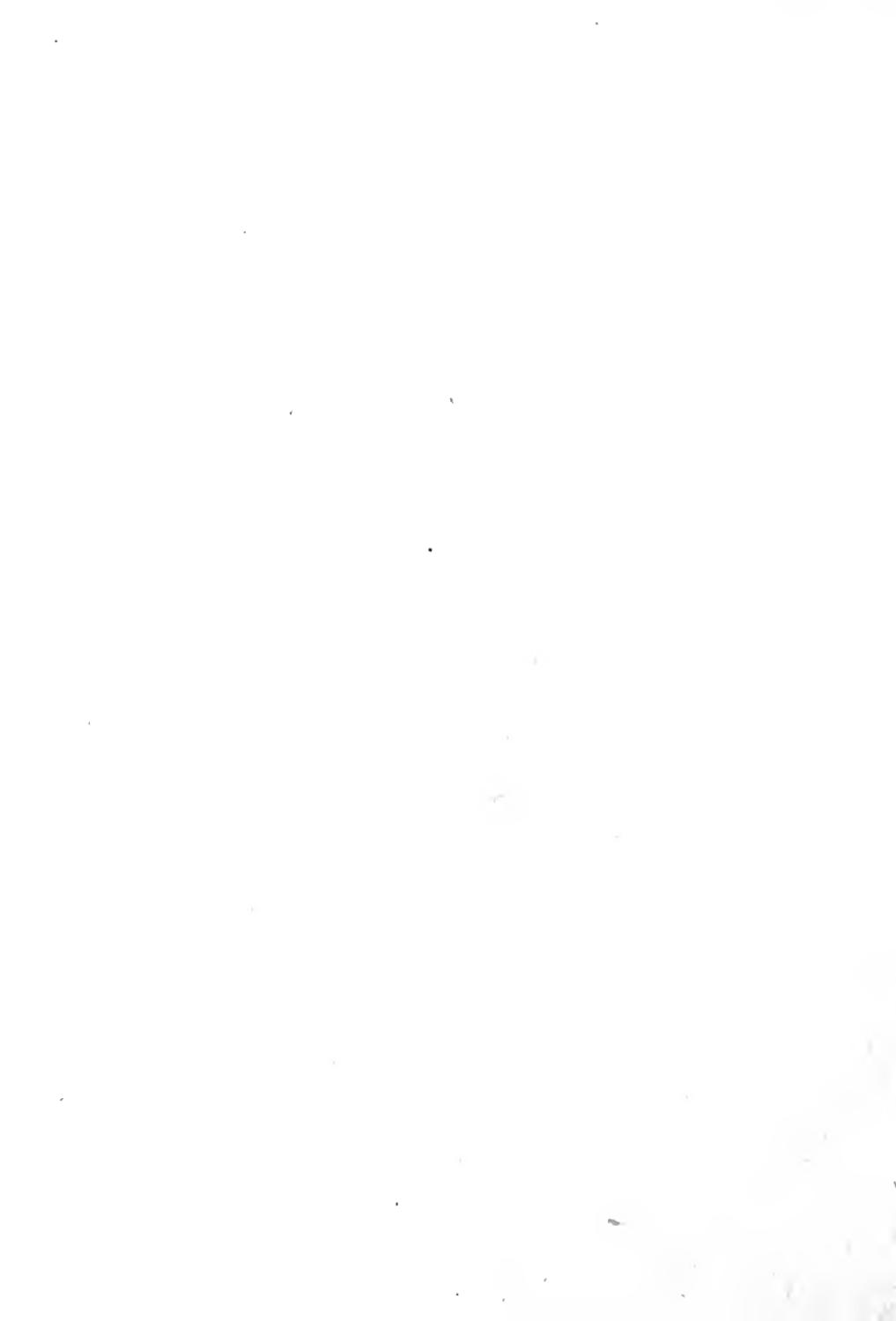
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A STUDY OF THE EFFECT OF  
TEMPERATURE AND PRESSURE  
ON THE CARBONATION OF WATER.

A THESIS  
PRESENTED BY  
WALTER L. MARX  
TO THE  
PRESIDENT AND FACULTY  
OF  
ARMOUR INSTITUTE OF TECHNOLOGY  
FOR THE DEGREE OF  
CHEMICAL ENGINEER

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A STUDY OF THE EFFECT OF  
TEMPERATURE AND PRESSURE  
ON THE CARBONATION OF WATER.

The carbonating industry, although not of recent origin, is still in its infancy as far as technical knowledge of the subject is concerned.

Statistics show that less than three per cent of the one hundred thousand bottling concerns in this country employ technically trained men. Almost complete chaos seems to exist in the minds of the great majority of bottling plant operators as far as scientific control of their process is concerned, and consequently a non-uniform product ranging from a non-palatable one to one of passable quality is thrust upon the public.

A great majority of the bottling plant operators--either on account of their indisposition to add the extra expense of a refrigerating system, or on account of their ignorance of the very important factor that temperature plays in the manufacture of a perfectly carbonated product--do not take the trouble to refrigerate their water, but simply carbonate it at whatever temperature they obtain it from their supply line.



Pressure alone will not produce a perfectly carbonated product if the temperature of the water during the impregnation period is above a certain limit.

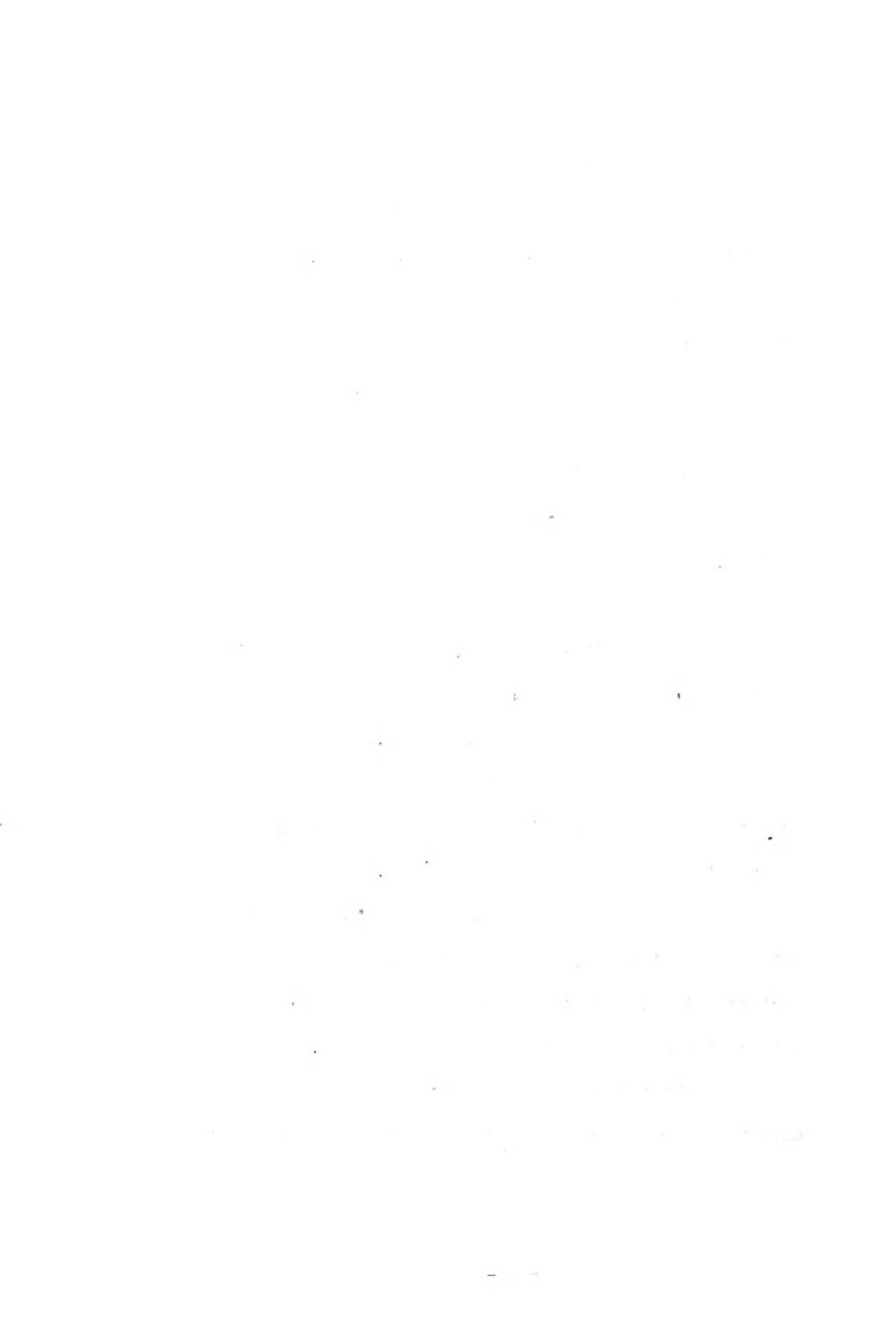
It has long been known by bottlers and by connoisseurs of carbonated water that the palatability of a carbonated beverage increases with age, and that a bottle of carbonated water will show a finer degree of combination between the carbon dioxide gas and the water six months or a year after it was carbonated than on the day that it was bottled.

Bottlers have also realized for a long time that they can obtain a finer degree of carbonation when bottling large size bottles, such as quarts, than they can when bottling small bottles, such as splits.

Both of the foregoing phenomena have been accepted as facts, and little or no effort has been made to ascertain the real underlying cause.

It was with this end in view that the author set out to determine, from a scientific standpoint, the factors which influence the degree of combination between the carbon dioxide gas and the water.

The author worked on the theory that a maximum amount of carbonic acid (  $H_2CO_3$  ) present in the water



produced a carbonated beverage of maximum quality.

The improper elimination of air from the carbonated water is to a very great extent instrumental in the manufacture of an imperfect product. At an ordinary temperature the pressure of air will not alone prevent the absorption of its own volume of carbon dioxide gas, but will represent twenty times the volume of the latter, due to their relative solubilities in water.

In conducting the research work, in order to determine the effect of temperature, pressure and time of storage on the degree of carbonation of the carbonated product, the author tested over twelve hundred bottles for bottle pressure and air content during a period of five months.

The carbon dioxide gas used was made from sodium bicarbonate and forty-two percent commercial sulphuric acid. The gas was then passed through two water purifiers in order to wash out any sulphuric acid or suspended material, and then through a potassium perman-ganate purifier in order to remove hydro-carbons which might be present. From the latter purifier the gas passed to a gasometer and was then ready for use.







The water was pumped from the spring through a block tin pipe to a nine hundred gallon glass lined supply tank on the second floor of the plant; from this tank the water gravitated through a series of refrigerating coils to the carbonator.

A Twitchell double pump carbonator was used for impregnating the water with the carbon dioxide gas. A description of this type of machine may be best given by tracing the passage of the water and the gas from the outlet of the refrigerating coils to the outlet of the carbonator.

In the illustration on the opposite page the refrigerating coils have been omitted between the gasometer and the carbonator, on account of the lack of space.

The outside shell of the gasometer is composed of galvanized sheet iron and is filled about two thirds full of water, which acts as a seal for the gas. In the illustration, part "8" shows the gasometer bell which is made of tin lined sheet copper. This bell is counter-weighed by means of the weight "4". As the gas passes from the generator through the purifiers into the gasometer inlet "1" the bell "8" rises. As soon as the carbonator has been put into operation, the gas is pumped from the



gasometer through the outlet "3" and passes through the gas refrigerating coils to the carbonator through the connecting pipes "h" and "f". The pipe line "f" conducts the gas from the single supply line "h" to both pumps, one on either end of the carbonator.

The mechanisms on both ends of the carbonator are identical in construction, and for this reason an explanation of one end will suffice for an understanding of the machine.

The water supply line is not shown in the illustration, but is practically the same as the gas supply lines "h" and "f". The water enters the water box at the rear of the carbonator through the inlet "k". The height of the water in this reservoir is regulated by means of a float. From the water box the water passes through the connecting pipe "l" to the pumps, the amount pumped being determined by the setting of the regulating valve "r". The gas regulating valve "17" is always kept wide open.

With each stroke of the pump a charge of water and gas is drawn from the supply lines and forced into the expansion dome "q"; from here it passes through the connecting pipes, through the check valve "b" into the spray chamber "c". In this chamber the water is divided into



a very fine mist by forcing the charge through a spraying apparatus into the carbonating cylinder "a". As the water falls into this cylinder, it is agitated by means of an agitator which revolves on the shaft "a7".

The pressure within the carbonating cylinder, as shown by the pressure gauge "s", is regulated by means of the pressure regulator "z". Any excess gas which is forced into the carbonating cylinder passes back through a blow back into the water box and saturates the water in the water box at atmospheric pressure. From here the excess gas passes through the gas return pipe, and the gasometer inlet "2" back into the gasometer.

When bottling at one pressure, both pumps are discharged into one carbonating cylinder by adjusting the distributing valves of the machine. The carbonated water is discharged from the carbonator through the outlet cock "v".

All of the water was filled on a Hes & Keller counter pressure type of rotary filler. When using this type of filler, the water is reduced in pressure after leaving the carbonator, by means of a pressure reducing valve before entering the filler, to twenty pounds. The water chamber of the filler is supplied with a floating disk, which regulates the height of the water within the chamber.



As the bottles are placed on the filling spouts, the water is allowed to flow into the bottles by forcing each of the twelve spouts to a downward position, thus opening the water valves. When the bottles are full, the pressure within the bottles and the filling chamber become equal and the flow of the water ceases.

From the filling apparatus the bottles pass to a crowning machine, and after being exposed to the atmosphere for a very brief interval they are crowned.

The crowned bottles are then put in galvanized iron steaming trays and are passed through a testing tank. This tank is supplied with a conveyor and is kept full of water at a temperature of 105 degrees F. As the crowned bottles pass through the tank, the temperature of the carbonated product is raised and the expanding of the carbon dioxide gas exerts a pressure of about fifty pounds per square inch on the crown. If the latter is defective in any way the escaping gas bubbles from the bottle through the water of the testing tank and the bottle is discarded.

In collecting the samples for the research work, every possible precaution was observed which would in any way affect the final results. The gas in the gasometer was frequently tested for purity by means of a



nitrometer and caustic potash solution and at no time was found to contain less than 99.3 per cent of carbon dioxide. The gas was also tested for sulphur trioxide by passing a stream of the gas through a hot solution of barium chloride, and not even a trace of sulphur could be detected.

The pressure regulator on the carbonating cylinder was set at 30 lbs. pressure and the carbonated water was allowed to flow out until it registered 32 degrees F. The bi-pass valve on the carbonator was then closed, the outlet to the filler was opened, and the carbonated water was allowed to flow out of the filler through a bi-pass valve until the constant temperature of 38 degrees F. was obtained. A series of twelve samples were then collected at this temperature and pressure.

The pressure regulator was then set at 40 lbs. and the same routine was followed as above without changing the temperature.

By keeping a constant temperature of 32 degrees F. and by increasing the pressure by 10 lbs. after each set of samples had been collected until a carbonating pressure of 70 lbs. had been reached, the whole series of 32 degrees F. samples were obtained.



The pressure regulator was then set back to 30 lbs. again, the temperature of the water was raised to 34 degrees F., and a series of samples were collected at this temperature.

The same routine was then followed until a series of samples had been collected for the various pressures ranging from 30 to 70 lbs. for the temperatures 36, 38 and 40 degrees F.

The foregoing pressures were used in collecting the six and one half ounce samples or splits. In collecting samples of the twelve and twenty-four ounce bottles the pressures used were 30 lbs., 45 lbs., 60 lbs., and 75 lbs. at the same temperature intervals as above.

During the time that the samples were collected, the air--which was displaced from the water by the gas during the process of carbonation--was allowed to escape from the carbonator through the air exhaust cap "d".

The sample bottles were then stored in a room where it was hoped that the temperature would be almost constant throughout the year; but this condition was not realized, as the tabulated forms of the results will show.

At the end of each month four samples, representing every condition of temperature and pressure under which the water was carbonated, were taken; and two were tested for







bottle pressure by means of a bottle pressure gauge, an illustration of which--together with an illustration of the nitrometer apparatus used for determining the amount of air in the bottled product--is given on the opposite page.

The bottle pressure testing apparatus is composed of three parts: the gauge--supplied with a piercing point,--the stuffing box, and the clamping mechanism. The latter is screwed on to the bottle to be tested, and the stuffing box is then clamped into place on the top of the bottle. The piercing point of the gauge, consisting of a tapering hollow steel tube, is then inserted in the stuffing box; and the stuffing box nut is tightened in order to prevent the escape of any gas and the consequent loss of pressure. The top of the hollow tube is provided with an outlet valve through which the gas is conducted from the bottle to the nitrometer.

After the testing gauge has been clamped in place on the bottle, the crown of the bottle is pierced by giving the top of the gauge a sharp blow with the hand, and the pressure within the bottle is registered on the gauge.

The pressure obtained in this way represents the saturation pressure of the product within the bottle.



If the contents of the bottle is now thoroughly agitated, the pressure will rise from five to fifteen pounds. This latter pressure represents the actual pressure of the gas within the liquid and is one of the two factors which determine the real percentage of carbonation of the product, the other factor being the temperature of the liquid.

The former is referred to by the trade as top pressure, while the latter is called liquid pressure.

In some types of filling apparatus--known as high pressure fillers--where the crown is clamped on the bottle immediately after filling, while the liquid within the bottle is still under pressure, the top pressure is greatly in excess of the liquid pressure on account of the entrained air.

However, in the type of filling apparatus as described in the first part of this article, the liquid within the bottle comes to atmospheric pressure at the filling temperature, when the bottle passes from the filler to the crowner. Any excessive air which may be in the bottle during filling is expelled during the brief exposure to the atmosphere. In this type of apparatus the top or saturation pressure is from five to fifteen pounds less than the liquid pressure.



In each case the saturation pressure was first recorded and the contents of the bottle was then well agitated and the liquid pressure recorded. The difference between the two pressures was tabulated as degree saturation at 60 degrees temperature.

Barring any abnormal bottles or any defective crowns, it was found--after making the necessary temperature corrections--that for any given carbonating temperature and pressure, the saturation and liquid pressures did not vary any during the entire time that the experiments were conducted.

Knowing that the presence of air in the carbonated product had a deleterious effect upon the latter, the author worked on the theory that the reason for the product improving with age was the displacement of the air in the water by the carbon dioxide gas and by subsequent formation of carbonic acid. According to the author's idea, this displaced air would--on account of its lower specific gravity than carbon dioxide--be forced to the top of the bottle, and would be drawn off with the first one hundred cubic centimeters of gas taken from the bottle for analysis.

With the arrangement of the testing apparatus, as



shown in the illustration, a second series of bottles were tested for the amount of air present in the first one hundred cubic centimeters of gas drawn off at the end of each month.

Every precaution which could possibly affect the result of experiment was taken. The small piece of rubber tubing connecting the pressure testing apparatus with the nitrometer was filled with water in order to eliminate the air in the tube. The water, which was used in the nitrometer, was saturated with carbon dioxide at atmospheric pressure, and a fresh supply of this water was used for each determination.

The samples of gas taken for analysis were collected as follows: the bottle pressure testing apparatus was clamped in position on the bottle to be tested, and the free end of the rubber tubing was attached to the outlet cock of the testing gauge. The crown of the bottle was then pierced by forcing the tube of the apparatus down through the crown. The pressure of the contents of the bottle in the quiscent state was then recorded, and the outlet cock of the pressure testing apparatus was appended. As soon as one hundred cubic centimeters of gas had been collected in the nitrometer, the outlet cock on the testing apparatus was closed and the two way stop cock on the nitrometer was



opened, the caustic potash solution passing into the nitrometer tube. After all of the carbon dioxide gas had been consumed and the water failed to rise any higher in the nitrometer tube, the leveling bottle was raised until the water level in the bottle was on a level with the top of the water column within the tube. The amount of air was then recorded.

Another series of bottles were tested for total air content in the following manner: the contents of the bottles was well agitated before the crowns were pierced and the resulting pressures were recorded. The first one hundred cubic centimeters of gas were then analyzed for air and the results recorded.

A representative number of samples were then tested in the following manner in order to determine the amount of air left in the bottle after the first one hundred cubic centimeters of gas had been removed, so as to compute a correcting factor for each size bottle, the addition of which, to the results obtained from the first one hundred cubic centimeters taken, would give the total amount of air in the bottle. - -

Consecutive samples of one hundred cubic centimeters each were taken from each bottle until the air had been entirely exhausted, a condition which was practically



obtained after one thousand cubic centimeters of gas had been taken off, and which was shown by the last gas sample registering practically 100 percent carbon dioxide. The results obtained from each bottle were then added, and the amount of air obtained in the last nine hundred cubic centimeters was, in most cases, practically a constant, but was found to vary with each size of bottle.

The average results obtained in determining these factors are as follows:

S P L I T S

<u>Volume of gas taken</u>	<u>Volume of air</u>
2nd. 100 cc.	.84
3rd. 100 cc.	.45
4th. 100 cc.	.43
5th. 100 cc.	.41
6th. 100 cc.	.40
7th. 100 cc.	.20
8th. 100 cc.	.12
9th. 100 cc.	.10
10th. 100 cc.	.05
Total....3.00 cc.	

P I N T S

<u>Volume of gas taken</u>	<u>Volume of air</u>
2nd. 100 cc.	.195
3rd. 100 cc.	.52
4th. 100 cc.	.50
5th. 100 cc.	.40
6th. 100 cc.	.41
7th. 100 cc.	.40
8th. 100 cc.	.20
9th. 100 cc.	.10
10th. 100 cc.	.05
Total....3.53 cc.	

Q U A R T S

<u>Volume of gas taken</u>	<u>Volume of air</u>
2nd. 100 cc.	1.20
3rd. 100 cc.	.70
4th. 100 cc.	.65
5th. 100 cc.	.60
6th. 100 cc.	.60
7th. 100 cc.	.40
8th. 100 cc.	.35
9th. 100 cc.	.20
10th. 100 cc.	.10
Total....4.80 cc.	



The results obtained were all tabulated and the calculations made as follows:

One U.S. liquid oz. is equivalent to 29.574 cc.

The volume of water in a quart bottle therefore equals

$$24 \times 29.574 \text{ cc.} = 709.77 \text{ cc.}$$

Recourse was then had to a table published by W. P. Heath of Atlanta, Ga., which gave the volumes of carbon dioxide gas absorbed by water for different temperatures and pressures. In this way it was found that one of the bottles which showed a bottle pressure of 37 lbs. at 60 degrees F. contained 3.77 volumes of gas or  $3.77 \times 709.77 \text{ cc.}$  or 2675.8 cc. of gas.

The first one hundred cubic centimeters of gas contained 10.7 cc. of air; this, with the correcting factor of 4.8 cc. added, gave 15.5 cc. as the total air content of the bottle.

The per cent of air was then calculated as follows:

$$\frac{15.5 \times 100}{2675.8} = .579\%$$

The total air in each bottle was calculated in the same manner and the results were tabulated.

The results obtained from the analysis of the first one hundred cubic centimeters taken from the bottle without agitating the contents were tabulated as "Air in first 100 cc."



Curves were then plotted embodying all of the results obtained during the entire series of experiments.

Two sets of pressure curves were plotted for each size of bottles,--one set having carbonating pressures as abscissas and saturation pressures as ordinates, and the other having carbonating pressures as abscissas and liquid pressures as ordinates.

A set of curves was also plotted with "total air content" as ordinates and carbonating pressures as abscissas.

Three curves, one for each size bottle, were plotted with "per cent of air in the first hundred cubic centimeters at saturation pressure" as ordinates and time of storage as abscissas. The data for the last three curves was taken for the carbonating temperature of 32 degrees F. and the carbonating pressure of 60 lbs.

The nature of most of the pressure curves were practically identical, as was also that of the "total air content" curves. A discussion of a few of these will therefore suffice for a thorough understanding of the results obtained from the entire experimental work.



The result obtained from the analysis of the total air in the bottle substantiated the author's theory that the elimination or retention of air by the water was largely instrumental in determining the efficiency of carbonation of the product.

If the results--obtained from the analysis of the total air in the three size bottles: quarts, pints and splits--are inspected, it becomes evident at once why a great deal finer degree of carbonation is obtained in a large size bottle than in a smaller one. The latter contained on an average of about 1.75% of air, while the quarts contained on an average of .4%. These amounts of air may seem to the reader to be too small to have any decided influence on the palatability of the water; but--when it is taken into consideration that each volume of air present in the water not alone displaces its own volume of gas, but represents twenty times the volume of the latter--it becomes evident that the amount of air given in the tables is not as trivial as what it seems at first sight.

By referring to the table of pressures on page 25, the effect of the more perfect elimination of air



from the quarts than from either the pints or splits becomes evident. Both the saturation and liquid pressures of the bottles tested show a marked increase for a decrease in the air content, varying from a twenty-six per cent increase of the pints over the splits to an increase of about thirty-five per cent of the quarts over the latter. In other words, the more perfect elimination of air from the large size bottles than from the smaller size bottles produced about one third more carbonation when comparing the quarts and splits, and about a quarter more carbonation when comparing the pints with the latter.

A study of the pressure table shows that both the saturation and liquid pressure vary directly as the carbonating pressures and as the volume of water bottled, and inversely as the carbonating temperature.

For any given temperature, the increase in either saturation or liquid pressures is not at all in proportion to the increase in carbonating pressure, and is less marked for the higher temperatures than for the lower.

From the foregoing conclusion, it will be seen that the pressure loss at filling is a good deal greater for water carbonated at high temperatures and pressures



than for the water carbonated at low temperatures and pressures. This latter statement must not be interpreted to mean that the author advises the use of a low carbonating pressure, but rather that the loss of pressure when carbonating at high pressure is disproportionately greater than when carbonating at low pressures.

The difference between the saturation and liquid pressures, which was recorded as "amount of saturation," is practically constant for all sizes of bottles and for all conditions of temperature and pressure.

After studying the data obtained from the pressure tests, it becomes evident that the best results are obtained when carbonating at 32 degrees F. with a pressure of 60 to 75 lbs.

Before discussing the "air content curves" the author wishes to explain the significance of each of the eight columns of data given on pages 36 to 38 inclusive from which the air content curves were plotted.

The results are given for each of the four months during which the work was done, and represents the averages of the duplicate samples tested for each determination.

Each sheet shows the data obtained from one size bottle carbonated at a given temperature and at pressures varying from 30 to 75 lbs. for the quarts and



pint sizes and from 30 to 70 lbs for the splits.

The second column on each sheet gives the number/ of cubic centimeters of air in the first hundred cubic centimeters of gas taken from the bottle at liquid pressure. The total number of cubic centimeters of air in the bottle was obtained by adding the constant, the derivation of which was explained on page 14--4.8 cc. for quarts, 3.5 cc. for pints and 3.0 cc. for splits--to the results given in the second column. The fourth and fifth column give the liquid pressures and the temperature at which the determination of air was made. The sixth column was obtained by referring to the table published by H. B. Heath of Atlanta, Ga., which gives the volumes of carbon dioxide gas absorbed by water at different temperatures and pressures. The liquid pressure given in column four and the temperatures in column five were used to obtain the results in column six.

The figures in column seven were obtained by dividing the total number of cubic centimeters of air, as given in column three, by the product of the contents of the bottle in cubic centimeters and the abstract gas volume figures in column six, and the results multiplied by one hundred. A sample calculation has been given on page 16.



The figures in column eight will be discussed later.

A study of the tables on pages 26 to 38 shows that the total air content of the bottled product varies inversely as the volume of the water bottled and directly as the carbonating temperature and inversely as the carbonating pressures. In other words, high carbonating pressures eliminate maximum amounts of air, while high temperatures cause a retention of maximum amounts of air.

Air being the cause of most of the trouble in carbonated products, the results obtained from this research work prove that the nearest approach to ideal results are obtained by having the carbonating temperature as low as possible and the carbonating pressure as high as can be obtained without making the cost of the process prohibitive. High pressures demand large amounts of carbon dioxide gas, a great percentage of which is lost during the filling process; and, as this loss increases disproportionately with the carbonating pressure, the latter should be limited to about seventy-five pounds for practical purposes. The last column of figures given in the tables gives the per cent of air in the first hundred cubic centimeters of gas taken from the bottle



at saturation pressure and represents the air which has been displaced in the water by the carbon dioxide gas.

According to the author's theory--on which this part of the research work was based--the amount of air in the first hundred cubic centimeters of gas taken from the bottle at saturation pressure would increase directly as the time of storage; but the results obtained were just the opposite.

This overthrow of preexpected results proved very puzzling to the author until recourse was had to the chemical analysis of the water, a copy of which is given on page 39. The item "oxygen consumed" undoubtedly explains the disappearance of a portion of the free oxygen contained in the bottled product, particularly so when the product was under fifty lbs. pressure.

Another item that was inspected was the iron present, which was found to be present in the water as  $FeO$  and most likely was oxidized to  $Fe_2O_3$  in the presence of oxygen under pressure.

The total air content in any given volume of bottled water--carbonated at any given temperature and pressure--theoretically should not vary at any time; but,



according to the results obtained, the total air content diminished with each succeeding month. This phenomena can also be explained by the oxidation of the ferrous iron to the ferric state.

Previous to the author's taking charge of the plant a great deal of trouble was had with the appearance of a precipitate in the water after it had been on the market for about a year. This precipitate was found to be partially composed of algea, but also of other matter which was not determined at the time. It was discovered by the author that a very poor grade of gas was being manufactured, due to improper elimination of air from the apparatus, which fault has since been remedied.

During the author's entire tenure of office it has been his custom to determine the quality of the carbonating gas previous to starting bottling operations, and at no time has gas been used which contained a prohibitive amount of air. Consequently there has not been a single complaint on account of the appearance of any suspended matter in the bottled product.



Bottle pressure in lbs. per square inch at 60 degrees F.

		Saturation pressure for carbonating temp. of					Liquid pressure for carbonating temperature of					Amount of saturation for carbonating temp. of				
		<u>32</u> <u>34</u> <u>36</u> <u>38</u> <u>40</u>					<u>32</u> <u>34</u> <u>36</u> <u>38</u> <u>40</u>					<u>32</u> <u>34</u> <u>36</u> <u>38</u> <u>40</u>				
		<u>Degrees</u> .....					<u>Degrees</u> .....					<u>Degrees</u> .....				
SPLITS -	30	31	30	27	27	29	36	35	33	32	32	5	5	5	5	3
	40	32	30	29	28	28	37	35	34	34	33	5	5	5	6	5
	50	33	32	30	28	29	39	39	37	36	35	6	7	7	8	7
	60	37	35	32	30	30	41	41	39	39	38	4	6	7	9	8
PINTS -	70	39	28	34	31	30	43	42	41	41	40	5	4	7	10	10
	30	39	36	34	33	33	46	38	35	35	35	7	2	1	2	2
	45	42	38	37	35	36	52	41	40	38	34	6	3	2	3	2
	60	46	41	39	38	38	54	45	41	41	38	8	4	2	3	0
QUARTS -	75	48	45	42	41	40	57	54	52	49	45	9	9	10	8	5
	30	42	40	37			50	45	42			8	5	5		
	45	45	44	42			53	48	46			8	4	4		
	60	48	46	44			55	51	49			7	5	5		
	75	50	49	47			57	55	54			7	6	7		



Carbonated at 32 degrees F.

Carbonation pressure in lbs. per sq. inch.	Cc. of air in 1st. 100 cc. of gas at sq. pressure	Total cc. of air in bottles.	Liquid degrees Fahr.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st 100 cc. of gas at sat- uration press.
30	8.3	11.3	20	54	2.56	2.30
40	10.1	13.1	35	54	3.66	1.86
50	8.5	11.5	32	54	3.45	1.73
60	5.0	8.0	30	54	3.30	1.25
70	6.5	9.3	30	54	3.30	1.47

1st month

30	8.8	11.8	30	64	2.79	2.20
40	7.2	10.2	24.5	64	3.07	1.56
50	5.4	8.4	28	64	3.65	1.19
60	7.0	10.0	35	64	3.10	1.68
70	8.6	11.6	35	64	2.83	2.13

2nd month

30	8.8	10.8	40	59	3.73	1.51
40	6.6	11.6	37	59	3.54	1.70
50	5.7	8.7	35	59	3.40	1.33
60	8.4	11.4	45	59	4.06	1.45
70	8.7	11.7	40	59	3.73	1.63

3rd month

30	7.8	10.8	40	59	3.73	1.51
40	6.6	11.6	37	59	3.54	1.70
50	5.7	8.7	35	59	3.40	1.33
60	8.4	11.4	45	59	4.06	1.45
70	8.7	11.7	40	59	3.73	1.63

4th month

30	9.6	12.6	28	60	3.86	1.70
40	9.5	12.5	40	60	3.66	1.78
50	7.9	10.9	32	60	3.13	1.81
60	6.8	9.8	40	60	3.66	1.40
70	6.5	9.5	33.5	60	3.23	1.55



Carbonated at 34 degrees F.

Carbonation  
pressure in  
lbs. per sq.  
inch.

1st. 100 cc.  
of gas at liqu.  
pressure

Co. of air in  
1st. 100 cc.  
of air in  
bottles.

Total cc.  
of air in  
bottles.

% of air in  
1st 100 cc. of  
gas at satur-  
ation press.

1st month

	Total cc. of air in bottles.	Liquid degrees Fahr.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in bot- tles.	% of air in 1st 100 cc. of gas at satur- ation press.
30	9.5	12.5	28	60	2.86	2.28
40	9.1	12.1	35	60	3.33	1.90
50	8.4	11.4	36	60	3.39	1.75
60	7.9	10.9	36	60	3.59	1.67
70	7.1	10.1	35	60	3.35	1.56

2nd month

30	8.9	11.9	21	54	2.72	2.28
40	9.3	12.5	24	54	2.97	2.16
50	8.3	11.3	32	54	3.45	1.70
60	8.6	11.6	34	54	3.60	1.67
70	8.5	30	54	54	3.30	1.34

3rd month

30	7.1	10.1	23	56	2.70	1.95
40	8.1	11.0	26	56	2.90	1.99
50	7.9	10.9	38	56	3.76	1.51
60	8.3	11.3	34	56	3.50	1.69
70	8.3	11.3	37	56	3.70	1.59

4th month

30	9.8	12.8	30	62	2.91	2.28
40	7.8	10.8	35	62	3.23	1.74
50	7.2	10.2	35	62	3.23	1.64
60	7.5	10.3	35	62	3.23	1.66
70	6.7	9.7	37	62	3.36	1.59



SPLITSCarbonated at 30 degrees F.

Carbonation pressure in lbs. per sq. inch.	Ccc. of air in 1st. 100 cc. of gas at liq. pressure.	Total cc. of air in bottles.	Liquid pressure.	Temp. in degrees Fahr.	Volume of gas in bottles.	Total % of air in 1st. 100 cc. of gas at saturation press.	% of air in 1st. 100 cc. of air in bottles.
<u>1st month</u>							
30	15.1	18.1	25	60	2.66	3.54	14.8
40	12.7	15.7	29	60	2.90	2.92	12.9
50	11.7	14.7	34	60	3.27	2.34	11.6
60	9.7	12.7	34	60	3.27	2.04	10.6
70	12.2	15.2	37	60	3.47	2.28	9.2
<u>2nd month</u>							
30	13.0	16.0	22	56	2.64	3.16	14.2
40	10.6	13.6	31	56	3.27	2.16	12.0
50	9.4	12.4	34	56	3.44	1.87	12.1
60	6.6	9.6	35	56	3.50	1.43	10.1
70	7.5	10.5	33	56	3.41	1.60	8.5
<u>3rd month</u>							
30	11.2	14.2	30	56	3.12	2.37	13.7
40	10.9	13.9	30	58	3.12	2.33	11.6
50	10.2	13.2	33	58	3.29	2.09	10.8
60	9.2	12.2	35	58	3.46	1.84	9.5
70	6.2	11.2	34	58	3.40	1.71	8.4
<u>4th month</u>							
30	9.7	12.7	28	62	2.87	2.30	13.5
40	9.2	12.2	45	62	4.00	1.59	11.2
50	8.9	11.9	35	62	3.35	1.86	10.0
60	10.4	13.4	42	62	3.80	1.84	9.3
70	10.5	11.3	37	62	3.47	1.70	8.6



S P L I T SCarbonated at 36 degrees F.

Carbonation Cc. of air in Total cc. Liquid Temp. in Volume Total %  
pressure in 1st. 100 cc. of air in 1st. 100 cc. of  
lbs. per sq. of gas at liq. bottles. gas at satur-  
inch. pressure.

% of air in  
1st. 100 cc. of gas at satur-  
ation press.

1st month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.
30	11.4	14.4	28	2.86
40	12.8	15.8	34	3.27
50	10.9	13.9	36	3.35
60	9.6	12.6	28	2.86

2nd month

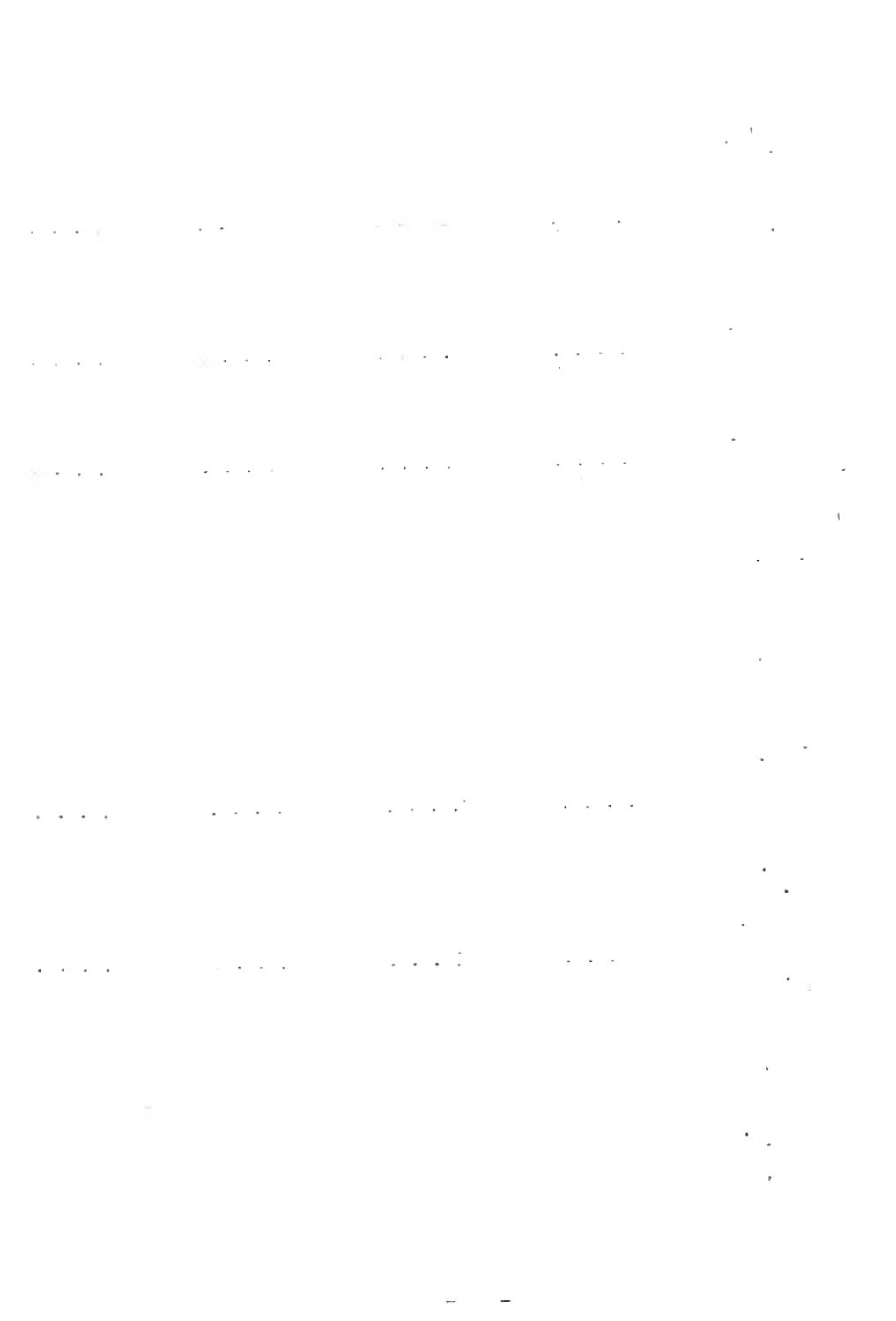
	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.
30	10.7	13.7	30	3.06
40	9.6	12.6	30	3.06
50	10.2	13.2	32	3.20
60	9.6	12.6	31	3.12

3rd month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.
30	12.2	15.2	36	3.39
40	11.9	14.9	36	3.39
50	10.0	12.0	37	3.47
60	10.9	12.9	38	3.53

4th month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.
30	6.4	11.4	30	6.2
40	9.8	12.8	30	6.2
50	8.4	11.4	32	6.2
60	8.4	11.4	45	6.2



SPLITSCarbonated at 40 degrees F.

Carbonation  
pressure in  
lbs. per sq.  
inch.

Cc. of air in  
1st. 100 cc.  
of gas at liq.  
pressure.

Total cc.  
of air in  
bottles.

Liquid  
pressure  
degrees  
Fahr.

Total %  
of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

12.0  
10.7  
9.4  
13.4  
10.8

15.0  
13.7  
12.4  
16.4  
13.8

27  
33  
35  
40  
45

60  
60  
60  
60  
60

2.80  
3.19  
3.33  
3.60  
4.00

3.76  
2.24  
1.94  
2.38  
1.80

10.9  
10.1  
9.8  
9.5  
8.8

1st month

30  
40  
50  
60  
70

12.0  
10.7  
9.4  
13.4  
10.8

15.0  
13.7  
12.4  
16.4  
13.8

27  
33  
35  
40  
45

60  
60  
60  
60  
60

2.80  
3.19  
3.33  
3.60  
4.00

3.76  
2.24  
1.94  
2.38  
1.80

10.9  
10.1  
9.8  
9.5  
8.8

2nd month

30  
40  
50  
60  
70

14.2  
12.9  
11.5  
10.4  
8.1

17.2  
15.9  
14.5  
13.4  
11.1

26  
28  
31  
40  
36

52  
52  
52  
52  
52

3.22  
3.26  
3.48  
4.16  
3.86

2.78  
2.55  
2.30  
1.68  
1.50

10.6  
9.7  
9.1  
8.4  
7.9

3rd month

30  
40  
50  
60  
70

12.6  
10.0  
11.8  
13.9  
9.2

15.6  
13.0  
14.8  
16.9  
12.2

32  
31  
33  
33  
37

58  
58  
58  
58  
58

3.26  
3.18  
3.32  
3.32  
3.60

2.49  
2.13  
2.39  
2.65  
,1.76

10.4  
9.6  
8.8  
8.1  
7.5

4th month

30  
40  
50  
60  
70

12.2  
12.4  
11.6  
10.0  
8.8

15.2  
15.4  
14.6  
13.0  
11.8

30  
32  
35  
37.5  
45

60  
60  
60  
60  
60

3.00  
3.13  
3.33  
3.50  
4.00

2.64  
2.56  
2.28  
1.94  
1.59

9.7  
8.1  
8.8  
8.0  
7.6



PINTSCarbonated at 32 degrees F.

Carbonation  
pressure in  
lbs. per sq.  
inch.

Cc. of air in  
1st. 100 cc.  
of gas at 14.  
pressure.

% of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

% of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

1st month

Cc. of air in 1st. 100 cc. of gas at 14. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	13.3	16.8	34	60	3.27
45	12.6	16.1	44	60	3.94
60	11.2	14.7	44	60	3.94
75	10.6	14.1	48	60	4.19

2nd month

Cc. of air in 1st. 100 cc. of gas at 14. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	13.4	16.9	26	68	2.37
45	11.7	15.2	50	68	3.77
60	11.5	15.0	48	68	3.65
75	10.4	13.9	50	68	3.77

3rd month

Cc. of air in 1st. 100 cc. of gas at 14. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	10.7	14.2	45	70	3.40
45	8.4	11.9	42	60	3.80
60	8.3	11.8	56	70	4.02
75	8.2	11.7	48	60	4.19

4th month

Cc. of air in 1st. 100 cc. of gas at 14. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	11.8	15.3	36	64	3.16
45	10.6	14.1	45	64	3.72
60	10.2	13.7	47	64	3.84
75	10.2	13.7	57	64	4.46



PINTS

Carbonated at 34 degrees F.

Carbonation  
pressure in  
lbs. per sq.  
inch.

Qc. of air in  
1st. 100 cc.  
of gas at liq.  
pressure.

Total cc.  
of air in  
bottles.

% of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

Total %  
of air in  
gas at satu-  
ration press.

1st month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in gas at satu- ration press.
30	12.4	15.9	34	60	3.27
45	10.5	13.8	35	60	3.33
60	8.5	12.0	27	60	2.78
75	9.5	13.0	44	60	4.94

2nd month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in gas at satu- ration press.
30	10.9	14.4	35	68	2.90
45	10.0	13.5	38.5	68	3.10
60	9.5	13.0	42.0	68	3.31
75	7.7	11.2	45.0	68	3.48

3rd month

	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in gas at satu- ration press.
30	11.5	15	36	60	3.39
45	8.1	11.6	37	60	3.47
60	6.8	10.3	38	60	3.53
75	9.1	12.6	45	60	4.00

4th month

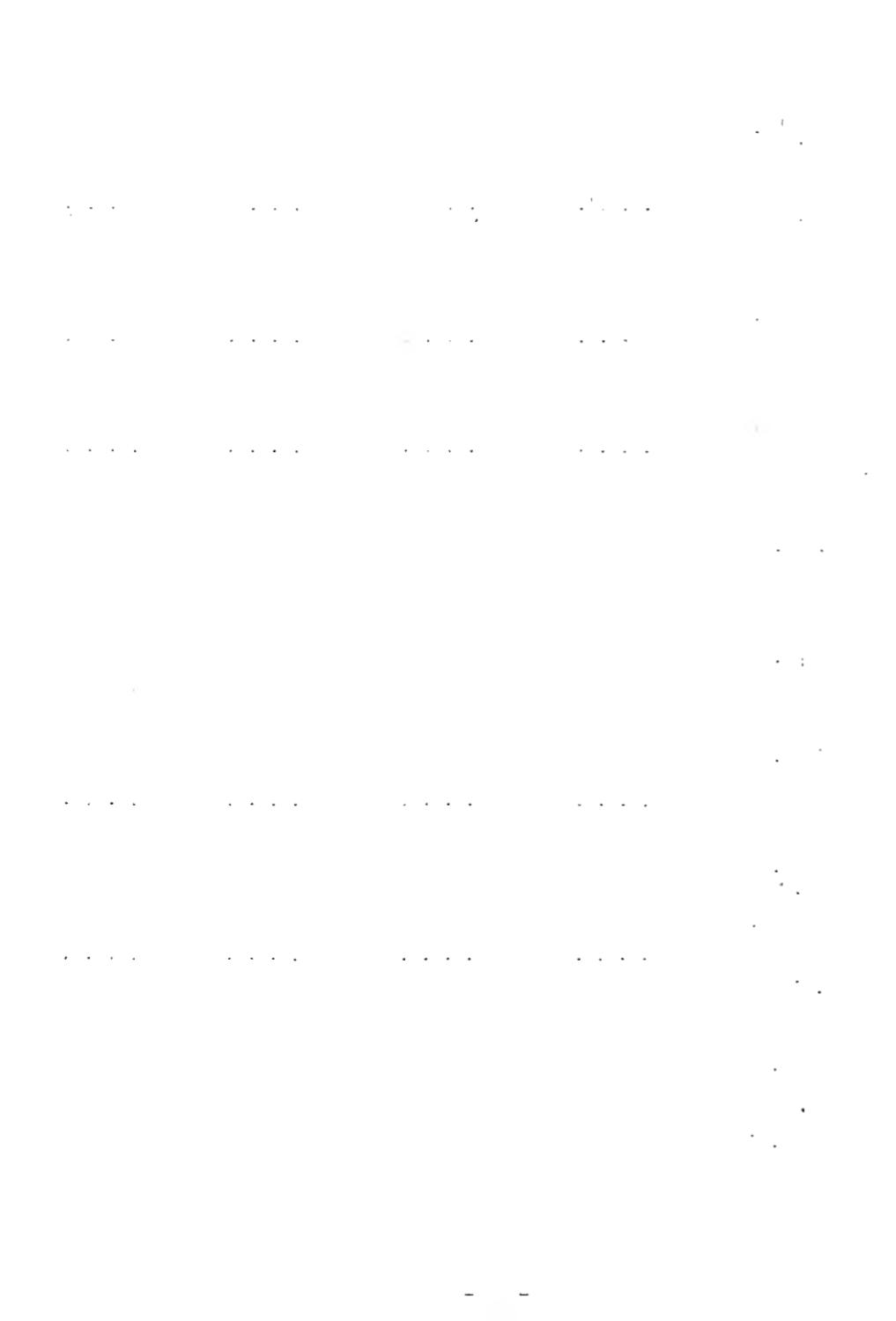
	Total cc.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in gas at satu- ration press.
30	8.8	12.3	32	64	2.91
45	8.6	12.1	33	64	2.97
60	7.8	11.3	34	64	3.04
75	6.6	10.1	42	64	3.53



## PINTS

Carbonated at 36 degrees F.

Carbonation pressure in lbs. per sq. inch.	Cc. of air in 1st. 100 cc. of gas at liqu. pressure.	Total cc. of air in bottles.	Liquid pressure	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in bot- tles.	% of air in 1st. 100 cc. of gas at satur- ation press.
<u>1st month</u>							
30	9.6	13.1	34	60	5.27	1.15	9.6
45	10.6	14.1	41	60	3.72	1.06	11.8
60	11.5	15.0	38	60	3.53	.91	11.5
75	9.1	12.6	40	60	1.06	.87	9.1
<u>2nd month</u>							
30	13.0	16.5	40	68	3.19	1.46	12.9
45	10.7	14.2	47	68	3.59	1.11	10.7
60	10.2	13.7	49	68	3.71	.98	10.2
75	7.6	11.2	50	68	3.77	.83	9.9
<u>3rd month</u>							
30	5.5	9.0	35	66	3.00	.84	11.7
45	8.9	12.4	50	66	3.90	.89	9.9
60	11.1	14.6	52	66	4.02	1.02	10.0
75	6.7	10.2	49	66	3.84	.75	—
<u>4th month</u>							
30	10.2	13.7	45	64	3.72	1.01	10.2
45	9.8	13.5	44	64	3.66	1.02	9.8
60	10.6	14.1	50	64	4.02	.99	10.6
75	6.4	9.9	48	64	3.90	.46	10.0



PINTSCarbonated at 38 degrees F.

Carbonation pressure in lbs. per sq. inch.	Cc. of air in 1st. 100 cc. of gas at liq. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
<u>1st month</u>						
30	11.7	15.2	39	60	3.60	1.19
45	11.2	14.7	45	60	4.00	1.03
60	11.0	14.5	38	60	3.53	1.15
75	10.7	14.2	39	60	3.60	1.11
<u>2nd month</u>						
30	11.2	14.7	42	60	3.80	1.09
45	8.9	12.4	46	60	4.06	.86
60	10.7	14.2	47	60	4.13	.97
75	10.2	13.7	43	60	4.86	.80
<u>3rd month</u>						
30	10.8	14.3	39	68	3.13	1.29
45	9.8	13.3	43	68	3.37	1.12
60	10.5	14.0	53	68	3.94	1.00
75	10.9	14.4	48	68	3.65	1.11
<u>4th month</u>						
30	11.2	14.7	36	64	3.28	1.26
45	10.8	14.3	45	64	3.72	1.08
60	10.6	14.1	50	64	4.02	.99
75	9.4	12.9	50	64	4.02	.90



PINTSCarbonated at 40 degrees F.

Carbonation  
pressure in  
lbs. per sq.  
inch.

Cc. of air in  
1st. 100 cc.  
of gas at liqu.  
pressure.

Total cc.  
of air in  
bottles.

% of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

Total %  
of air in  
1st. 100 cc. of  
gas at satur-  
ation press.

1st month

	Total cc. of air in bottles.	Liquid pressure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air of gas in bot- tles.	% of air in 1st. 100 cc. of gas at satur- ation press.
30	12.5	16.0	35	60	3.33	1.35
45	11.9	15.4	41	60	3.72	1.16
60	9.7	13.2	44	60	4.94	.75
75	9.8	15.3	42	60	3.80	.96

2nd month

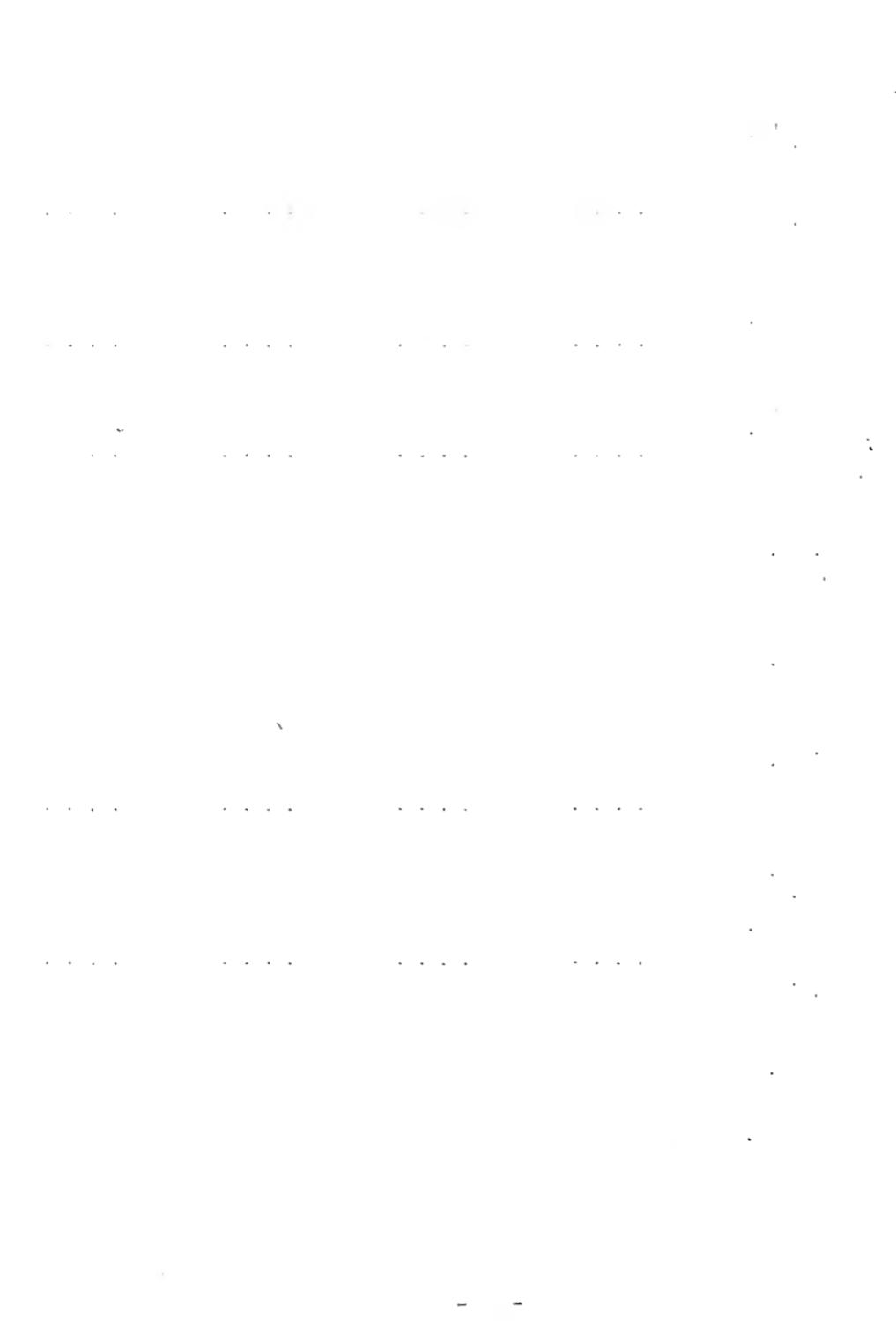
	Total cc. of air in bottles.	Liquid pressure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air of gas in bot- tles.	% of air in 1st. 100 cc. of gas at satur- ation press.
30	13.3	16.8	36	60	3.39	1.39
45	8.4	11.9	43	60	3.86	.87
60	8.2	11.7	46	60	4.06	.81
75	9.5	13.0	45	60	4.00	.91

3rd month

	Total cc. of air in bottles.	Liquid pressure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air of gas in bot- tles.	% of air in 1st. 100 cc. of gas at satur- ation press.
30	12.5	16.0	45	68	3.48	1.29
45	9.5	13.0	39	68	3.13	1.17
60	8.7	12.2	46	68	3.54	.97
75	9.3	12.8	51	68	3.83	.94

4th month

	Total cc. of air in bottles.	Liquid pressure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air of gas in bot- tles.	% of air in 1st. 100 cc. of gas at satur- ation press.
30	12.6	16.1	38	64	3.28	1.38
45	9.4	12.9	37	64	3.22	1.13
60	7.2	10.7	37	64	3.22	.63
75	9.8	14.3	48	64	3.90	.70



QUARTSCarbonated at 32 degrees F.

Carbonation pressure in lbs. per sq. inch.	Cc. of air in 1st. 100 cc. of gas at liq. pressure.	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at sat. press.
<u>1st month</u>						
30	10.7	15.5	50	68	3.77	11.8
45	8.4	12.9	50	68	3.77	11.4
60	8.5	12.8	52	68	3.88	11.2
75	7.8	12.5	55	68	4.05	9.7
<u>2nd month</u>						
30	7.8	12.6	35	54	3.66	4.65
45	6.1	10.9	38	54	3.87	4.00
60	5.8	10.6	38	54	3.87	3.87
75	6.0	10.8	42	54	4.18	3.65
<u>3rd month</u>						
30	9.5	14.3	37	60	3.47	5.82
45	11.8	16.6	43	60	3.86	6.07
60	9.8	14.6	41	60	3.72	5.57
75	9.6	14.4	46	60	4.06	5.00
<u>4th month</u>						
30	8.2	13.0	50	60	4.33	4.24
45	7.6	12.4	55	60	4.66	3.76
60	7.8	12.6	40	60	3.66	4.86
75	6.8	11.6	55	60	4.66	3.50



QUARTSCarbonated at 34 degrees F.

Carbonation pressure in lbs. per sq. inch.	Cc. of air in 1st. 100 cc. of gas at liq. pressure.	Total cc. of air in bottles.	Liquid pressure bottles.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at sat. pressure.	% of air in 1st. 100 cc. of gas at sat. pressure.
<u>1st month</u>							
30	10.2	12.0	35	60	3.33	.636	10.6
45	8.3	13.1	37.5	60	3.50	.528	8.7
60	7.5	12.3	35	60	3.33	.520	7.5
75	7.0	11.8	41	60	3.70	.450	7.0
<u>2nd month</u>							
30	13.2	16.0	35	54	3.66	.695	12.2
45	9.7	14.5	36	54	3.70	.553	10.0
60	6.8	11.6	31	54	3.34	.490	6.4
75	7.3	12.1	37	54	3.80	.450	7.5
<u>3rd month</u>							
30	11.5	16.3	46	62	3.94	.584	11.2
45	7.5	12.3	48	62	4.07	.427	8.1
60	9.9	14.7	45	62	3.88	.535	6.8
75	7.4	12.2	55	62	4.50	.362	9.1
<u>4th month</u>							
30	8.8	13.6	45	60	4.00	.480	8.8
45	6.6	13.4	50	60	4.33	.456	8.6
60	5.4	10.2	45	60	4.00	.360	5.4
75	7.2	12.0	50	60	4.35	.391	7.2



Q U A R T SCarbonated at 36 degrees F.

Carbonation  
Pressure in  
lbs. per sq.  
inch.

Cc. of air in  
1st. 100 cc.  
of gas at liq.  
pressure.

Total cc.  
of air in  
bottles.

Liquid  
pres-  
sure.

1st month

	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	11.4	16.2	29	60	2.92 11.4
45	8.5	13.3	35	60	3.33 5.64
60	10.0	14.8	42	60	3.80 10.5
75	9.0	13.8	40	60	3.66 10.4

2nd month

	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	14.5	19.3	28	54	3.14 14.5
45	10.0	14.8	34	54	3.60 10.0
60	8.5	13.3	35	54	3.66 10.2
75	7.4	12.2	35	54	3.66 9.9

3rd month

	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	9.6	14.4	42	69	3.52 9.6
45	6.9	11.7	45	69	3.52 7.6
60	7.6	12.4	52	69	3.37 7.9
75	7.9	12.7	54	69	4.03 7.9

4th month

	Total cc. of air in bottles.	Liquid pres- sure.	Temp. in degrees Fahr.	Volume of gas in bot- tles.	Total % of air in 1st. 100 cc. of gas at satur- ation press.
30	9.8	14.6	45	60	4.00 9.8
45	7.4	12.2	45	60	4.00 7.4
60	6.8	11.6	50	60	4.33 6.8
75	8.2	13.0	45	60	4.00 8.4



CHEMICAL ANALYSIS OF WATER

	Parts per 1,000,000	Grains per U.S.Gallon
Potassium Oxide	4,990	0.29181
Sodium Oxide	14,380	0.84094
Lithium Oxide	Trace	Trace
Phosphoric Acid Radicle	None	None
Sulphuric Anhydride	21.840	1.27719
Silica	11.800	0.69006
Iron and Alumina (Iron Oxide Alumina)	0.071 2.029	0.00415 0.11865
Lime	107.550	6.28947
Magnesia	58.932	3.44631
Arsenic Acid Radicle	None	None
Metaboric Acid Radicle	Trace	Tracd
Bromine	None	None
Iodine	None	None
Barium	None	None
Strontium	None	None

HYPOTHETICAL FORM OF COMBINATION

	Parts per 1,000,000	Grains per U.S.Gallon
Potassium Chloride	7.895	0.46169
Sodium Chloride	1.508	0.08818
Sodium Sulphate	31.087	1.81795
Magnesium Sulphate	6.517	0.38111
Magnesium Bicarbonate	205.811	12.03573
Calcium Bicarbonate	310.795	18.18421
Iron Oxide	0.071	0.00415
Alumina	2.029	0.11865
Silica	11.800	0.69005
Sodium Metaborate	Trace	Trace
Lithium Chloride	Trace	Trace
Iron	0.050	0.00292
Chlorine	4.556	0.27228
Nitrites	0.001	0.00005
Nitrates	None	None
Free Ammonia	0.032	0.00187
Albuminoid Ammonia	0.070	0.00409
Hardness before boiling	273.600	16.00000
Hardness after boiling	109.200	6.38596
Organic and Volatile	20.000	1.16959
Mineral Matter	335.000	19.59064
Total Solids	355.000	20.76023
Oxygen Consumed	1.175	0.06871



B I B L I O G R A P H Y

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J. C. Grossmann, M. E.

The Carbonic Acid Industry.

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Chemical Abstracts.

























